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# A STUDY OF THE OPEN HEARTH

A TREATISE ON THE OPEN HEARTH FURNACE  
AND THE MANUFACTURE OF  
OPEN HEARTH STEEL

BY  
HARBISON-WALKER REFRACTORIES CO.  
PITTSBURGH  
1909

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## PREFACE



**R**EALIZING as we do that only by a full understanding of all the conditions encountered in actual Open Hearth practice, can refractory materials be so manufactured as to maintain the highest standard for such work, we have made this study of Open Hearth steel furnaces and their operation essentially for the use of our Operating Department.

So much interest in this article, however, has been shown by a number of Open Hearth superintendents, who have suggested it as being of interest to iron and steel men generally, that we have decided to publish it in this form.

This study claims no originality. Its aim is to put into as concise form as may be, the principles involved, together with such detailed description as may render the subject matter plain to one familiar with no more than the most elementary principles of chemistry and metallurgy. Other articles will be issued from time to time on blast furnaces and hot blast stoves, heating and puddling furnaces, etc., any or all of which may be obtained by a request to be put on our mailing list.



# A STUDY OF THE OPEN HEARTH

## CHAPTER I

### STEEL

Definition: In possibly no other industry has there been so much disputation, and to so little avail, as in the steel industry over a correct and all-comprehensive definition of steel as distinguished from wrought iron. Committees, national and international, have been appointed and their recommendations made, but changes in processes of manufacture and in current commercial usage have made these recommendations void of practical value.

Previous to modern methods of steel manufacture, such as the Bessemer and the Open Hearth, hardening or tempering in water indicated steel; failure to harden, wrought iron. However, with the advent of these processes, a large part of their output, universally recognized as steel, fails to come within the terms of such description.

It is seemingly impossible to formulate a definition that will exactly fit every case, but in general that given by Campbell, as being that in common commercial usage, although but a definition by process rather than characteristics, seems best, namely:

(1) Wrought iron is the product of the puddle furnace.

(2) Steel is the product of the cementation process or the malleable compounds of iron made in the crucible, converter or open hearth.

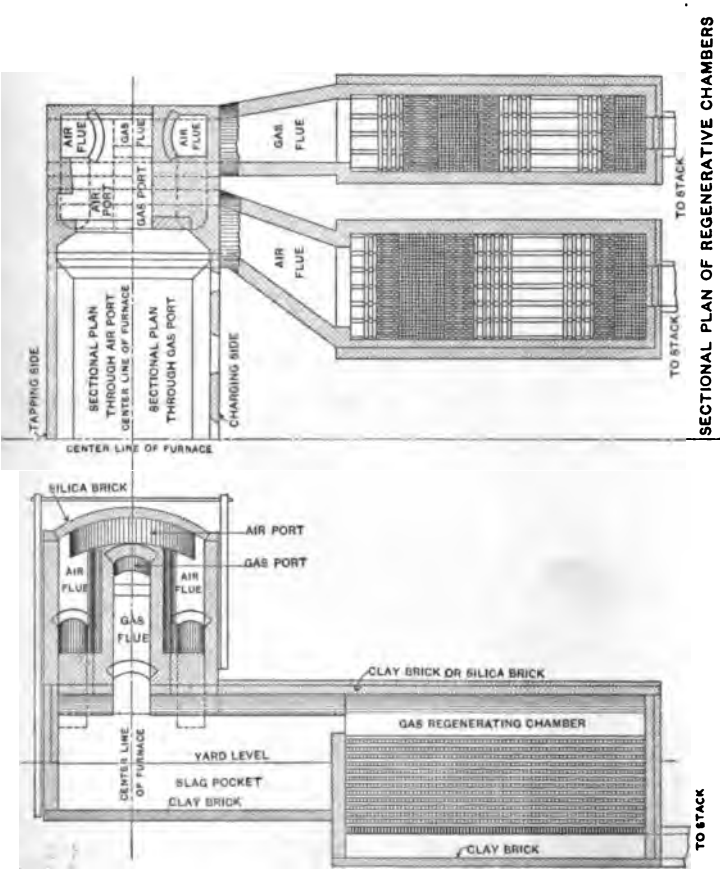


**MODERN OPEN HEARTH FURNACE**

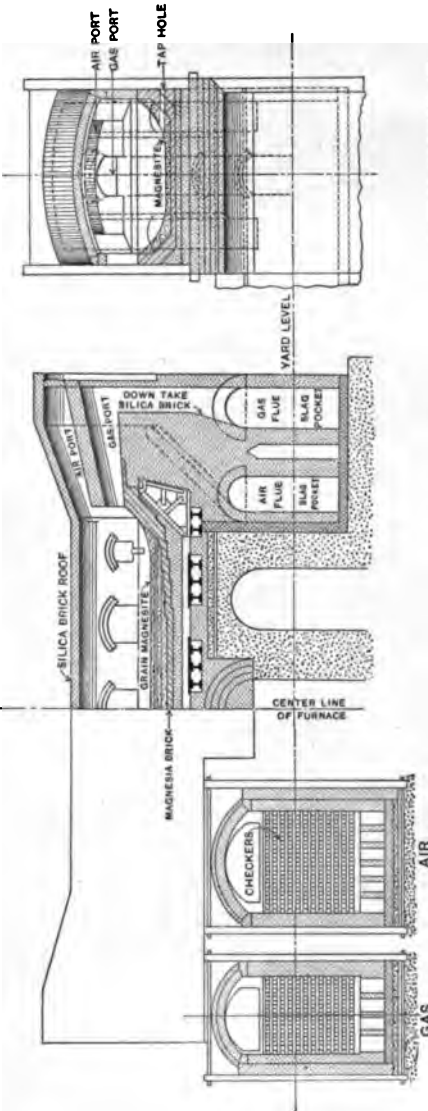
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**AUG. 20, 1909.**



**SECTION THROUGH PORTS AND REGENERATIVE CHAMBER**



TRANSVERSE SECTION AT  
CENTER LINE OF FURNACE

LONGITUDINAL SECTION AT  
CENTER LINE OF FURNACE

TRANSVERSE SECTION OF  
REGENERATIVE CHAMBERS

## A STUDY OF THE OPEN HEARTH

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### PROCESSES OF MANUFACTURE

There are practically but three processes of steel making:

(1) Crucible, invented in Sheffield, England, by Huntsman in 1740.

(2) Bessemer, invented by Henry Bessemer in 1855. Priority over Bessemer in the invention of this process is claimed by an American, Kelly, although his American patent was applied for in 1857, about a year after Bessemer's American patent was allowed and two years after his English patent. Kelly's application was granted on grounds of priority, but considerable litigation ensued, a compromise finally being effected.

(3) Open Hearth, by Charles, William and Frederick Siemens in 1861.

The crucible process, because of its necessarily high cost, is restricted to high grade steel for cutlery, tools, intricate parts of machinery, etc.

The Bessemer process, quantitatively until the year 1908 the leading process of steel manufacture, is unquestionably giving way to the Open Hearth, and there is comparatively small chance that we shall in the future see any new Bessemer plants of importance.

This is due primarily to the growing scarcity of ores from which can be made pig either sufficiently low in phosphorus for the acid Bessemer or sufficiently high for basic Bessemer. In the acid process none of the phosphorous being removed, we are limited to such pig as contains *only an amount* of phosphorous allowable in the



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finished steel. On the other hand, in the basic Bessemer, this element must be sufficiently high, say  $2\frac{1}{2}$  to 3 per cent., to supply with the manganese and carbon fuel to oxidize and keep hot the charge, otherwise a "cold heat" will result.

The Open Hearth now manufactures more steel than any other process, and is undoubtedly destined to make still greater strides, its relative tonnage as compared with Bessemer is here indicated:

1898	{	6,609,017	.	.	.	Bessemer
		2,230,292	.	.	.	Open Hearth
1899	{	7,586,354	.	.	.	Bessemer
		2,947,316	.	.	.	Open Hearth
1900	{	6,684,770	.	.	.	Bessemer
		3,398,135	.	.	.	Open Hearth
1901	{	8,713,302	.	.	.	Bessemer
		4,656,309	.	.	.	Open Hearth
1902	{	9,138,363	.	.	.	Bessemer
		5,687,729	.	.	.	Open Hearth
1903	{	8,592,829	.	.	.	Bessemer
		5,829,911	.	.	.	Open Hearth
1904	{	7,859,140	.	.	.	Bessemer
		5,908,166	.	.	.	Open Hearth
1905	{	10,914,372	.	.	.	Bessemer
		8,971,376	.	.	.	Open Hearth
1906	{	12,275,830	.	.	.	Bessemer
		10,980,413	.	.	.	Open Hearth
1907	{	11,667,549	.	.	.	Bessemer
		11,549,088	.	.	.	Open Hearth
1908	{	6,116,755	.	.	.	Bessemer
		7,780,872	.	.	.	Open Hearth

As compared with the Bessemer, its operations are under greater control, samples can be taken at frequent intervals and thoroughly tested, there is much less danger of over-oxidization and as a whole its product is more uniform.



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and reliable. The yield of ingots compared with the total of metal charged is also, as compared with the Bessemer, higher.

### DESCRIPTION OF OPEN HEARTH FURNACE

Inasmuch as with the exception of the bottom lining, the furnace for both basic and acid Open Hearth practice is identical, this description applies to each, with the exceptions noted, and assumes a producer gas fired furnace.

\*The furnace<sup>(FIGURE 1)</sup> consists of a rectangular bath, hearth or basin, open at each end for the admission of gas and air at the ports. This hearth is arched by a roof from 9 inches to 12 inches in thickness. At each end of the furnace are two checker chambers, one for the pre-heating or regeneration of the air, the other of the gas. Before starting the furnace a wood fire is built in one set of chambers<sup>(OR IN THE FURNACE)</sup> and after these have attained a dull red heat the gas and air are passed through them, entering at one end of the furnace, are deflected downward by the direction of the ports, unite in combustion over the hearth, and the gases, the products of combustion, leave the furnace through the ports at the opposite end, passing downward through the checkers or regenerative chambers, there giving up their heat to the checkers, thence through the flues to the stacks.

At frequent intervals, say from 15 to 20 minutes, dependent on the quality and amount of fuel, charge, working of furnace, etc., the



## A STUDY OF THE OPEN HEARTH

currents of gas and air are reversed, now entering the furnace at the opposite ends and having passed through the checker chambers, heated up during the previous period, take this stored up heat to create a more intense flame over the bath. These waste gases in turn pass out through the chambers, giving up their heat. This reversal is maintained with regularity until the charge is ready to tap.

It is evident that we have here, practically and theoretically, a constant increase of temperature, for at each successive reversal the gases pass through and over checkers hotter than at the previous pass, giving in turn a more intense heat in combustion and an increasing temperature in the chambers. Where there is a full charge of cold stock at the beginning of operations and the fuel is poor in quality or insufficient in quantity, these will, with the necessarily increased radiation as the furnace becomes hotter, keep the heats from being unduly high, but in general with the furnace properly working and with a good supply of gas, there is no difficulty in reaching and maintaining the desired temperature. The practical limit is merely what the brickwork of the furnace will stand. This temperature is controlled by proper regulation of the valves admitting gas and air to the flues.

The whole furnace is securely tied together by heavy I-beams or channels serving as buckstays and connected both top and bottom by tie-rods having turn buckles, these turn buckles

## A STUDY OF THE OPEN HEARTH

being adjusted as the furnace is heated up, thus allowing for the necessary expansion. In size the furnace varies with the output desired, from a 15-ton furnace or even considerably smaller, for special steels, up to 60 and 75 tons. Of the newer furnaces the 60-ton is probably the more usual size, it often producing up to 65 or even 80 to 90 tons per heat, and several 75-ton furnaces (nominally) are regularly taking off heats of 100 tons or over. As a usual thing, however, the preference is had for an increased number of units of say 50 or 60 tons, tapping at various intervals, as the output of ingots can be better taken care of than with units of larger capacity.

### DETAILS OF FURNACE

#### ROOF

The roof is invariably of silica brick. The highest grade cannot be too good, as to a very great extent both here and in the ports the tonnage of the furnace is dependent upon the life of the brick. The difference in actual brick cost between a mediocre and a high-grade brick is nothing as compared with the losses due to shutdown for necessary repairs and consequently decreased tonnage. The roof is in the majority of cases 9 inches thick, made of standard sized wedge and straight brick, but on the larger furnaces is often 12 or 13½ inches. Particularly in a roof of large span and low rise it gives structurally a much stronger design, an advantage *in construction* such as this where the roof is



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subjected to great and widely varying stresses due to temperature changes in the furnace.

Assume that a silica brick will wear or burn down to say 3 inches in thickness before the roof must be renewed (it will sometimes stand until 2 inches or even less remain), there then goes to the bat pile  $\frac{3}{4}$  or 33 $\frac{1}{3}$  per cent. of the brick, while if a 12-inch roof is used only  $\frac{3}{4}$  or 25 per cent. is wasted. By far the greater saving, however, comes in the increased life of the roof and consequent increased tonnage.

As compared with a roof 12 inches thick the increased radiation from a 9-inch roof once deemed necessary to prevent the melting of the silica brick, is entirely needless when the roof is constructed of the highest grade material, and so far as this point is concerned it may be any desired thickness. In certain portions of the furnace roof 18 to 20-inch sections are giving excellent results.

In the earlier types of furnace the roof was brought down very low over the hearth with the idea of keeping the flame in closer contact with it, but experience has shown that if too low the roof is rapidly burned away, proper combustion is retarded, there not being sufficient room for the proper development of the flame, and the impinging flame of the ports playing almost directly against the low drop roof, very soon cuts the latter away. The roof is usually now built of such ample height as to remedy these difficulties.



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In all modern furnaces the skew backs on which the roof arch rests are in turn supported on heavy channels, a part of the steel furnace frame. Thus the full thrust of the arch is here taken up, relieving the front and back walls of the furnace from any other than their own dead weight. Inasmuch as the front and back walls often require patching and renewal, the necessity of thus supporting the roof is apparent. In the old style of furnace the giving way of a wall meant the failure of the entire roof.

A number of furnace roofs are now constructed on a radius not only from front to back wall but also arched longitudinally, *i. e.*, from port to port. This has proven good practice, enabling the furnace to take care of expansion and contraction to good advantage and also giving a very strong construction.

### HEARTH AND BOTTOM

For proper operation it is imperative that the hearth be of such length as to allow full combustion over the bath proper, thus obtaining the full calorific value of the flame. Furthermore, if the hearth is of insufficient length there will be undue cutting of the ports as the gases leave the furnace, in some instances the gases in reality burning in the ports and upper portions of the checker work. This means excessive renewals, high fuel consumption and general wasteful operations. In one instance on account of the *defective proportioning* of the furnace, general

## A STUDY OF THE OPEN HEARTH

repairs were necessary every 300 heats, while with one properly proportioned 1200 heats is easily attained in acid practice.

Fifteen feet is usually considered the maximum width, as furnace operatives can hardly throw the refractory material for patching and daubing the back wall a greater distance than this. The length will usually be from 2 to  $2\frac{1}{2}$  times the width.

As to the depth of the hearth proper as finally lined up, it must be the happy medium between such shallowness as shall promote reasonably quick working of the bath and a maintenance of proper thermal conditions throughout its mass, and of such depth as will reduce the oxidation of metal to a minimum, avoiding overburned metal and a reduced percentage of output as compared with the metal charged. This balance is usually obtained with a depth of from 15 to 20 inches.

The entire bottom and hearth of the furnace is built in and supported by a pan of heavy riveted steel plates, supported in turn on I-beams or channels resting on piers and entirely independent of the regenerators or other parts of the furnace. Reasons for this will be later taken up.

### MATERIAL FOR BOTTOMS

It is here only that there is material difference between the acid and basic Open Hearth, this due to the nature of the slags carried in the acid

## A STUDY OF THE OPEN HEARTH

and basic processes respectively, and it is from the nature of these that the processes derive their names.

In the acid process the slag is made up of the silica sand adhering to the pig metal charged and the silica due to the oxidization of the silicon in the pig, as well as of the oxides of manganese and iron, these oxides forming during the working of the charge, and were a basic lining used in the bottom, there would of course be a reaction between the slag and lining, consequently an acid or neutral lining is used, while for basic practice a neutral or basic material is necessary to avoid reaction between the bottom and the slags rendered basic by the addition of lime for the removal of phosphorus and sulphur.

### ACID MATERIALS

The only acid material used is silica sand, all acid furnace bottoms being made from it. A natural sand is often used containing various percentages of silica, a typical analysis being, for instance:

Water . . . . .	.24 per cent.
Silica . . . . .	97.25 per cent.
Alumina and iron oxide . . . . .	.16 per cent.
Lime . . . . .	.08 per cent.
Magnesia . . . . .	.39 per cent.
Alkalies . . . . .	.36 per cent.
Loss on ignition . . . . .	.36 per cent.

Certain beach sands give very good results, *and there are also a number of deposits in the*



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West and Middle West, but it is impossible to predict by analysis alone the quality of a given sand. If of excessive purity there is difficulty in properly setting it in the furnace, and if the impurities run too high, although the sand will then easily frit or set, it is subject to great erosion in the operation of the furnace and will not make a sufficiently hard, dense bottom. The physical characteristics have a wide bearing on the question of its adaptability, and two sands of practically identical analysis may considerably differ as to their suitability for bottom work. Often a combination of two or more sands will secure the best results.

### NEUTRAL MATERIAL

*Carbon*, while almost perfectly resisting the action of the slag, is very rapidly destroyed on account of the great affinity of the metal for it. It has often been tried in the form of brick, as well as rammed with tar, and although the matter is again and again reviewed by those not familiar with previous experiments, its practical use is out of the question.

*Bauxite*, a hydrous oxide of alumina, analyzing approximately:

Silica	$\text{SiO}_2$	4 to 7 per cent.
Iron peroxide	$\text{Fe}_2\text{O}_3$	3 to 5 per cent.
Alumina	$\text{Al}_2\text{O}_3$	60 per cent.
Water	$\text{H}_2\text{O}$	30 per cent.

although exceedingly refractory, is subject to excessive shrinkage at furnace temperatures. It is

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very difficult to so calcine as to entirely eliminate this shrinkage, and when so calcined, all plasticity is lost through loss of its combined water. In modern Open Hearth practice it is never used.

*Chromite*, a sesqui-oxide of chromium, usually termed chrome ore, which has been rather more thoroughly tried out abroad than in this country, is extremely infusible and practically neutral, but its infusibility renders it very difficult to set or sinter thoroughly, and it has been found practically impossible to so thoroughly set the bottom that it will not be subject to mechanical erosion rather than any chemical reaction. It will analyze as follows:

Sesqui-oxide of

chromium .	$\text{Cr}_2\text{O}_3$	38 to 40 per cent.
Alumina .	$\text{Al}_2\text{O}_3$	24.5 per cent.
Iron peroxide	$\text{Fe}_2\text{O}_3$	17.5 per cent.
Silica .	$\text{SiO}_2$	3.25 per cent.
Magnesia .	$\text{MgO}$	15 per cent.

In spite of its high refractoriness it has, when selected with due regard to its analysis, and when properly prepared, a large and rapidly widening field in daubing and patching around the slag line, back walls, ports, jambs, etc.

Of course a neutral bottom would be the ideal one for Open Hearth practice, inasmuch as any change from the basic to acid process, or vice versa, could be made without change in the furnace, but as indicated above, the materials at our disposition do not allow a satisfactory neutral *working bottom*.



## A STUDY OF THE OPEN HEARTH

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### BASIC MATERIALS

*Lime*, or calcium carbonate,  $\text{CaCO}_3$ , is, in its calcined form,  $\text{CaO}$ , theoretically an excellent material for bottoms, but it is practically out of the question, due to the rapidity with which it slakes when exposed to air. When reheated, the rapid driving off of the gas and water reduces the lime to a powder, in which condition it is rapidly worn away.

*Dolomite*, a magnesian limestone, is one of the materials very commonly used for patching bottom, and in some cases even for the entire bottom, particularly by those to whom its comparatively low first cost appeals, but it is open to the same objection as lime, only in a lesser degree, *i. e.*, slaking on exposure to the atmosphere, and if a stock is more than ten days to two weeks old this becomes an important factor. Of course where the plant calcines its own dolomite this is a less important consideration. Furthermore, it is impossible to so set a dolomite bottom that it shall be as dense and vitreous as magnesite, and in spite of most watchful care portions of the bottom will from time to time become detached and float; in fact, within the last two or three days of this writing we have reports advising that the entire bottom in each of two furnaces has floated. In a dolomite bottom where, through erosion or absorption of metal, a hole or depression is once started, disintegration progresses with much more rapidity than with magnesite, and there is considerably

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more liability of serious breakouts. A fairly representative analysis of dolomite is as follows:

Silica . . . . .	5.52 per cent.
Alumina and iron . . . . .	3.74 per cent.
Calcium . . . . .	29.20 per cent.
Magnesia . . . . .	17.31 per cent.
Loss on ignition . . . . .	43.82 per cent.

In a number of instances the absorption of the impurities from the dolomite has proven an exceedingly serious matter in the manufacture of high grade steels and has resulted in an increased use of magnesite. Dolomite sets somewhat more rapidly than magnesite.

*Magnesium carbonate* ( $\text{MgCO}_3$ ), when calcined to the oxide,  $\text{MgO}$ , commercially known as magnesite, is unquestionably the best material for Open Hearth bottoms, and all original bottoms are now installed with it. Even by those using a large percentage of dolomite in repairing, it is admitted to be the best material available, absolutely the only argument in favor of dolomite being its low first cost. The well-known Austrian magnesite of the following approximate analysis

Silica . . . . .	$\text{SiO}_2$ . . . . .	2.84 per cent.
Alumina . . . . .	$\text{Al}_2\text{O}_3$ . . . . .	.929 per cent.
Iron peroxide . . . . .	$\text{Fe}_2\text{O}_3$ . . . . .	8.571 per cent.
Lime . . . . .	$\text{CaO}$ . . . . .	1.120 per cent.
Magnesia . . . . .	$\text{MgO}$ . . . . .	85.32 per cent.
Carbon dioxide . . . . .	$\text{CO}_2$ . . . . .	.50 per cent.

gives such a proportion of iron, etc., as makes *the material set* in the furnace bottom, forming



## A STUDY OF THE OPEN HEARTH

a hearth of maximum density, subject to minimum erosion by the metal, and practically unaffected by the slags. Furthermore, on indefinite exposure to the atmosphere almost no deterioration takes place, while with a dolomite bottom under like conditions, should furnace shut-down occur, the bottom would of necessity be renewed. The large deposits of Austrian magnesite insure ample supply for years to come.

*Grecian* magnesite has been used as a bottom material, but on account of its high refractoriness there is difficulty in fusing it in place, it being necessary to introduce impurities in the way of silica, clay, or oxide of iron in amounts sufficient to reduce its refractoriness. The resultant is too variable a quantity to give reliable results, and *Grecian* magnesite is very seldom employed.

### CONSTRUCTION OF ACID BOTTOM

#### TAP HOLE

In the center of the furnace wall, near the base on the tapping side, is left an opening from 15 to 20 inches square, arched over with silica brick. Into this opening is inserted a tapered plug the size of the finished tap hole. Around the plug is rammed ganister, and the plug being withdrawn the hole is almost filled from the charging side with lump anthracite coal, the remainder being rammed with fire clay from the





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outside, the furnace then being ready to make bottom.

### BOTTOM

Directly on the steel shell or pan forming the bottom is placed from one to three courses of silica or clay brick, preferably silica, and at the sides and ends of the furnace a number of additional courses stepped up as in the illustration, showing magnesia brick in the basic Open Hearth, page 11. The thickness of the sand bottom proper will then be approximately the same over the entire basin-shaped hearth. Over this brick is sometimes spread a thin layer of sandstone or granite clippings, while this is by no means invariable. The gas is then turned on, the heat gradually increased until the chips begin to soften or sinter, when a thin layer of sand, say one-half to three-quarters of an inch, is spread evenly over the hearth and the heat maintained at sufficient temperature to glaze over this coating of sand. Another layer is then spread and the process repeated until the entire bottom is built up to a thickness of 15 to 20 inches of this vitreous, glassy structure. The bottom is run well up the side wall to a distance of at least a foot above the slag line.

### WASH-HEAT

In order to thoroughly consolidate the bottom, it is usual to run what is termed a "wash-heat." This consists merely in melting a charge



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of acid open hearth slag and thoroughly washing down the banks of the furnace with it.

### CONSTRUCTION OF BASIC BOTTOM

#### TAP HOLE

This is made in much the same way as with an acid bottom, except that the hole is arched usually with magnesia brick and magnesite, rendered slightly plastic with anhydrous tar rammed around the form, or ground chrome ore may be used instead of the magnesite. The chrome ore when of proper analysis and properly set undoubtedly makes the best material for tapping holes, the hole itself being filled with magnesite or magnesite and dolomite mixed. This is tamped well into place by ramming against a rabble held against the inside of the furnace.

#### BOTTOM

On the steel shell forming the bottom of the furnace are placed two or three courses of first quality clay brick, then three or more courses of magnesia brick, the latter being carried well up the banks of the furnace and stepped off as in the case of silica brick with the acid furnace. Often a course of chrome brick is inserted between the clay and the magnesia brick, and sometimes no clay brick whatever are used here, merely the magnesia brick. The magnesia brick serve to greatly retard the breaking through of the metal, should the furnace bottom



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proper be cut through, and usually allows sufficient warning so that the charge may be tapped off before the metal actually breaks out.

In this connection it is in a number of foreign plants the custom to use a very much larger proportion of magnesia brick in the bottom than in this country, a comparatively small part only, say 6 to 8 inches, being made up of the sintered grain magnesite. The idea is, of course, that the brick are, due to their density and the fact that they have previously been burned at very high temperatures, more resistant to the passage of metal and slag. This is undoubtedly true. The question arises, however, as to how much this is offset by the necessary increase of joints, always an element of weakness where anything is encountered as fluid as molten steel and slag at the temperature of the open hearth furnace. So far as economy in the original installation is concerned, there is probably little to choose, inasmuch as although the brick are naturally expensive, yet the fuel costs in setting an entire bottom of grain magnesite are also high.

Directly on the magnesia brick is spread in a thin layer the grain magnesite. This is sometimes mixed with hot tar previous to its application to render it plastic, although this is not the usual custom. In order to hasten its setting, from 5 to 15 per cent of basic cinder is often introduced, the mixing being done on the charging floor by shoveling, much as cement and sand are mixed, *for instance*, one shovel of finely ground cinder to



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five of magnesite. The magnesite is then fused on the magnesia brick bottom in layers, in exactly the same way as is the sand on the acid furnace bottom, building up the front and back walls well above the slag line. With the furnace at melting heat, the material becomes pasty, and with a rabble it is a comparatively easy matter to shape the bottom and sides as desired.

### WASH HEAT

A wash heat of basic slag or of roll scale is charged, allowing it to melt and soak well into the bottom, tapping off the remainder. This not only prevents the later absorption of metal but considerably increases the density of the hearth.

### FRONT AND BACK WALLS

In the acid furnace the front and back walls are throughout of silica brick; in the basic, are silica from a few courses above the slag line up, but below this of magnesia brick. It was at one time almost universally the custom to insert between the basic magnesia brick in the front and back walls and the acid silica brick one or two courses of neutral chrome brick. However, many Open Hearths are now built and with apparent satisfaction without this neutral course, inasmuch as at the temperatures usually encountered in Open Hearth practice, there is little or no fluxing action between the magnesia and silica brick. However, it is unquestionably good practice to use chrome brick as indicated, as it is

## A STUDY OF THE OPEN HEARTH

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in effect an insurance against trouble due to chemical action, should the heats run considerably above normal temperatures, as they are of course liable to do, and a number of instances have been recorded where serious trouble has occurred due to omission of the neutral brick.

In basic practice the walls should be daubed with chrome ore finely ground, this preferably extending entirely to the skew line. It is an economy, as it almost wholly protects these walls from the action of the gases laden with dust, slag, limestone and iron oxide spray which otherwise very rapidly erodes them. Here again not all chrome ores are suitable, if too refractory the ore merely dries and rolls away, a suitable ore, however, shows marked plasticity and remains in place until thoroughly set.

### BULKHEADS

The mass of brick forming the ends of the furnace hearth is often termed the "bulkhead," and at one time it was the custom to build this in solid, of silica brick except for the facing of magnesia brick somewhat above the height of the slag line in the basic Open Hearth. However, in such a mass there is comparatively little radiation and the bulkhead very rapidly burned away. In modern furnaces this construction is replaced by a steel frame supporting the end walls of the hearth, so that comparatively few courses of brickwork are necessary, the *bulkhead then being* practically air cooled. This



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simple expedient has effected great savings not only in brick costs but in the operation of the furnace. In the best basic practice, it is now the custom to face the entire bulkhead of the furnace up to the ports with magnesia brick, or to bank it with lump or ground chrome ore, this giving in some instances fifteen or sixteen times the life of silica brick.

### PORTS

These are the openings through which the gas and air are admitted to the furnace, and the proper operation of the furnace is nowhere more dependent on good design than here. In the ports originate by far the larger proportion of Open Hearth furnace troubles, and even when perfectly designed as to size, arrangement and alignment, it is a difficult matter to keep them so. One or the other end of the furnace is continuously subject to the outgoing rush of incandescent gases laden with particles of ore, limestone, slag, etc., and at a comparatively high velocity due to diminution of area from that over the hearth to that of the ports. This action tends to cut back the ports very rapidly. In a large number of cases there are two gas and two air ports at each end of the furnace, although this is varied by one gas and two air, or two gas and three air, and in the majority of the large modern furnaces, one gas and one air port. Whatever may be the number, they are so arranged that the air, being heavier, shall

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enter above and outside the gas, the two then deflected downward by the alignment of the ports, spread and mingle at the port ends, combustion there taking place and the flame is distributed over the entire bath of metal.

The air being above and outside the gas, keeps the most intense heat away from the roof, and front and back walls, thus preventing the cutting action of the flame which, if directed against the roof, very rapidly burns it away. In this position also not only do the gas and air naturally mingle on account of their relative specific gravities, but the gas being lower, keeps the current of heated air from directly impinging upon the stock, which if allowed to occur would produce undue oxidization of the metal. The alignment is usually such as will make the gas and air meet slightly above the surface of the metal, approximately 3 feet, although it is often so designed that this will be at a point considerably higher, say 4 or 5 feet, but if the latter height is exceeded, there is a tendency for the flame to cut away the roof too quickly, and if lower than approximately 3 feet, combustion is somewhat retarded by the gases being chilled by the cold stock, and full development of flame prevented.

The importance of the details of port construction can be most easily comprehended by realizing that the gas and air ports together with the down-takes (vertical flues leading from the ports to the gas and air chambers) form merely an *ordinary gas burner* on a large scale, and from



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this point of view, the necessary and frequent adjustments as to the admission of gas and air appear very simple. As illustrating how comparatively small a matter may cause trouble in the operation of the furnace through port troubles, a certain Open Hearth roof burned out after 15 or 16 heats, the trouble occurring in one spot in the roof. On investigation this was found due to a silica bat which had been left lying in the gas port. The gas impinging on this brick, had been thrown in an eddy directly on the roof, causing the hot spot referred to. After the removal of the bat there was no further trouble.

The ports and blocks, that is the mass of brickwork forming the end of the furnace through which the ports extend, are ordinarily built up of silica brick, but due to the rapidity with which these ports cut away, numberless schemes have been tried for lengthening the life of this portion of the furnace. Among these is the water-cooled port constructed of bronze cooling plates, a type similar to that in ordinary use in blast furnace practice, with these plates forming the division wall between the gas and air ports, protected by one or more courses of magnesia or chrome brick. This has given in many cases very good results, affording much longer life than the ordinary one.

There are a number of other types of water-cooled ports, in some instances constructed by imbedding water cooled pipes in the port arch, this arch being made of ground magnesite or of



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ground chrome ore rammed over forms. In other cases, the arch is supported directly on water cooled pipes.

Instead of making the port of silica brick, some have used forms rammed with ganister, with a small quantity of binding clay, fusing it in place. This is an improvement in so far as it does away with the joints of the brick work, always an element of weakness, but in the majority of instances has not been found a substantial saving, as it burns back in the same manner as will the ordinary port. By far the most satisfactory method of extending the life seems to be to pave them with magnesia brick or fine ground chrome ore, and also daubing the face of the port with this, its plasticity enabling it to remain in place until sufficiently set.

### REGENERATORS

As to the location of the gas and air chambers or regenerators, these are now nearly always placed entirely independent of the furnace body proper. Formerly the chambers were directly under the body of the furnace, the furnace resting on them, and old furnace men still claim that with such construction a furnace works somewhat quicker than with the present type, but there are many decided objections. In the first place, with the furnace resting directly on the arches of the chambers, where there is necessarily more or less distortion due to changes in *temperature*, cracks are very easily opened up

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both in the furnace and chamber walls, and it is much more difficult to keep the construction gas and air tight. Second, any breakout allows the metal from the hearth to run directly into the checkers, filling them up and making an enormous amount of work before the furnace can be again put in commission. Third, repairs to one or the other, *i. e.*, furnace proper or regenerators, cannot be as well taken care of.

As to the proportions of air and gas chambers there is much discussion, in some of the older types they are made of practically the same size, but in all newer furnaces the air is considerably larger, roughly, the proportion being at least  $1\frac{1}{3}$  to 1. This is logically correct as regards the quantities required for proper combustion of the gas and air, and furthermore, the temperature of the air has considerably more bearing on the final temperature of combustion than has the gas. The exact proportion of the two, however, is not so important as that they be ample in size, the cubical contents, however, being by no means the only factor determining the proper working of this part of the furnace. In the best practice, the tendency is to have the chambers of greater height rather than secure the same volume with a low arch and increased length. This is due to the fact that the gases tend to rise and a more uniform draft is secured by having a sufficient quantity of checkers in the vertical direction rather than by making the gases travel for a considerable distance through long passages.

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Furthermore, the retardation due to the friction of air and gas does not become as important a factor. Roughly, the height should be, for a 60-ton furnace, from 13 to 18 feet and in cubic capacity, a very common allowance is 90 cubic feet per ton of steel.

At the bottom of the regenerators are usually placed what are termed "Regenerator" or "Girder" tile, these tile forming flues extending the complete length of the regenerators. On these tile are built up the standard 9-inch or small checker brick into a series of vertical flues having openings of  $3\frac{1}{2}$  to 4 inches. Other things being equal, the efficiency of the chambers is dependent upon the amount of surface of checkers heated, and consequently giving up their heat, but it is perfectly possible to over-do this matter, inasmuch as, if the openings between the brick are too constricted they very rapidly clog, due to accumulations of flue dust, etc., carried over by the gases, this meaning excessive shutdowns for repairs and cleaning. There has also been used in a number of furnaces a large checker,  $10\frac{1}{2} \times 4\frac{1}{2} \times 4\frac{1}{2}$  inches, this being used, however, only in chambers whose dimensions are especially designed for it. The advantage claimed is that with a brick of such size it can be used many times over, this effecting a considerable saving in brick costs.

On the other hand, many who have gone into the matter very thoroughly, claim that the brick *is of such size* that the interior portion does not



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come thoroughly heated by the time each reversal is made; in other words, that a certain inner portion of the brick is, while taking up the space in the regenerative chambers, inactive, and that with the same contents and with the same cubic capacity in the checkers, greater efficiency can be secured by increasing the regenerative surface, using smaller sizes, such as the 4 inch Straight and Standard Checker.

As to the kind of brick used for checkers, there are many variations suited to special conditions. In probably a majority of cases a first quality clay brick is used throughout. Still others use first quality for all except the top ten or twelve courses which are laid with silica brick, constantly increasing number using silica brick throughout. These, it is claimed, become choked very much less readily than do the clay brick, the carbon coating not seeming to penetrate and adhere to the brick as is the case with the clay brick. They often give several times the life of a clay brick.

In other instances, furnace men have found a marked benefit in the use of magnesia brick for the top five or six courses, the claims for them being the same as for silica, except that they are better even than the latter. Furthermore, magnesia and silica brick on top courses exert a marked influence on the quick working of the furnace, enabling the heats to be taken off somewhat faster. Others have applied a thin wash of very finely powdered chrome ore to the

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checkers, this rendering them less affected by the caking of slag, soot, etc. There is absolutely no question but what often a great economy in the operation of the furnace can be effected by the substitution of a first quality grade of checker brick for the inferior material sometimes used. The walls of the chambers should be made of first quality clay or silica brick, it often being advantageous to make the arches of silica brick, especially where the flues open into the chambers. Silica brick of course expand and tend to hold everything tight as the furnace is heated up. It also is considerably more refractory and will give much longer life. Where with the use of silica brick there is danger of spawling, due to sudden changes of temperature, it is found of great advantage to use an inner course of clay brick, laying the silica directly over this course. The silica brick then has opportunity to become gradually heated and is in fact thoroughly annealed before the clay brick burn away and the silica is exposed to the hot gases.

### SLAG POCKETS

The slag pockets, which are virtually but enlargements of the flues leading from the checker chambers to the uptakes and ports, are merely to intercept the fine particles of limestone, slag, ore, etc., carried over by the gases in their passage to the chambers. They also serve to take the slag, *should* the furnace boil or froth excessively. *Careful attention*, however, will usually keep



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such frothing down to a minimum by opening the doors and thus allowing the bath to cool slightly.

By use of slag pockets is avoided the constant cleaning out of checkers and possible entire stoppage of the furnace, should the slag boil over into the gas ports. They are so arranged with clean-out doors as to be very rapidly emptied without undue delay in furnace operation.

### UPTAKES OR VERTICAL FLUES

These lead from the ports to the slag pockets. They are usually lined with first quality clay brick, but it is coming to be more and more the practice to line them for the upper half or even the entire height with silica brick, and in some instances it has been advisable to line with magnesia brick, especially directly back of the port where the gases impinge against the back wall.

### HORIZONTAL FLUES

Horizontal flues, a continuation of the uptakes, are the passages leading from the slag pockets to the checker chambers, and from the checker chambers to the stack.

### GAS AND AIR VALVES

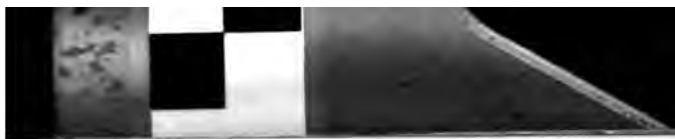
Gas and air are admitted to the flues by a simple form of throttle valve. In addition to this there is a reversing valve by which is controlled the reversal of the current through the two sets of checker chambers. The reversal valve in most common use is the old Siemens or

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"butterfly" valve, and this is still often installed. There have been a number of improvements on it. In any type of reversing valve, the valve casing encloses three openings, one to the stack and one each to the two chambers, gas and air. The "butterfly" valve has to recommend it its extreme simplicity of installation and operation as well as low first cost. Operating against it, however, is the fact that there is often considerable trouble due to warping of the valve occasioned by hot gases on one side and comparatively cool gases on the other. Although the temperature of the gases on their way to the stack is normally only from 400 to 700 degrees Fahrenheit, yet at times when the furnace is not operating properly, the heats will rise considerably, even to from 1000 to 1200 degrees Fahrenheit. Attempts have been made to remedy this by water-cooling the valve, but without great success. There is also at times leakage at the valve seat due to the deposit of soot and tar at the joints, which prevents the valve from closing tightly. The above points, as well as troubles from cracking of the cast iron box enclosing the valve, have induced the improvements made in the various types of water-sealed valves.

### DAMPERS

If the furnace were always working properly and the chambers entirely free and open as at the beginning of a run, there would be comparatively *small necessity* for dampers, but, as often happens,



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the chambers become partially choked, due to the accumulation of dust and soot, so that in order to effect an even distribution of heat it is necessary to damper down, otherwise one chamber will work considerably hotter than another. The damper is merely a rectangular plate loosely fitting in a frame set in the flues, this plate sliding in suitable grooves.

### STACKS

It is important that the stack have ample draft, it being an easy matter to damper down, but if the draft is insufficient, proper working of the furnace cannot be secured.

### SPECIAL FURNACES

#### TILTING OR ROLLING FURNACE

The tilting or rolling furnace differs from the ordinary stationary type in that the entire furnace body may be rotated or tilted through a considerable arc, thus pouring the entire heat or any portion of it at any stage of the process. This flexibility in operation is often of great value.

In one type the entire furnace body between ports revolves on a nest of rollers, the axis of revolution being coincident with a line drawn through the center of the ports, thus enabling the gas and air to be kept on regardless of the position of the furnace.

In another type the furnace in pouring, rocks or tilts away from this axis, thus breaking the



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connection with the ports, the gas and air necessarily being cut off with the furnace in pouring position.

These furnaces do away with a great portion of the tap hole troubles, the tap hole being above the metal and slag lines with the furnace in the normal position, and it is consequently only necessary to fill the tap hole with a very light tamping. They also enable the melter to thoroughly drain the furnace bottom of any slag or metal, it being in the stationary furnace often a difficult matter to rabble or splash out all depressions, and any portion of the heat left in such a hole very soon tends to permeate and disintegrate the surrounding bottom.

With the furnace tipped or rotated, the back wall being much nearer the horizontal plain, this wall may be patched with bottom mixture, and this patching extended much higher than on the stationary furnace, as the material will naturally adhere until set in much larger quantities than is the case with the almost vertical back wall of the ordinary type.

Where there is excessive frothing so that the slag tends to flow out the doors, the furnace may be tipped, thus keeping the metal away from the working doors. In one type of tilting or rolling furnace, any excess of slag is allowed to run out through small holes in the bottom of the port openings.



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### CHAPTER II

#### FUELS

The fuels to-day in use in Open Hearth practice are natural gas, artificial gas and oil.

#### NATURAL GAS

By far the best and most satisfactory from every point of view is natural gas, but this of course is restricted within a comparatively small area. Its advantages aside from its cheapness where available, lie in its higher calorific value, with consequent increased tonnage of the furnace; its purity, there being no sulphur, etc., to be carried over and absorbed by the steel; and its cleanliness and convenience in operation, it requiring no heating previous to its introduction into the furnace. It is also very constant in quality and the furnace can be in every way operated to its best advantage.

When natural gas was first introduced it was attempted to run it through the gas chambers to preheat it in the same way as producer gas, but it was found that due to the high percentage content of hydro-carbons, the heavier hydro-carbons deposited on the checker walls a vitreous gummy coke which very soon clogged the checkers and interfered with the regenerative effect of the checker work.

Although artificial gas is far more generally important, due to the restricted area in which natural gas is available, yet in some comparatively recent years nearly 50 per cent. of the

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Open Hearth tonnage has been made with natural gas.

The following average analyses of natural and producer gas will show very clearly the reasons for the superiority of the former:

Constituent	Formula	Percentages		
		Natural Gas, 8.65 Per Cent. Air	Natural Gas, 0 Per Cent. Air	Producer Gas
Carbon dioxide .	CO <sub>2</sub>	.40	.45	5.7
Carbon monoxide	CO	1.70	1.85	22.
Oxygen . . . .	O	1.80	.0	.4
Ethylene . . .	C <sub>2</sub> H <sub>4</sub>	1.40	1.55	.6
Ethane . . . .	C <sub>2</sub> H <sub>6</sub>	12.95	14.20	.0
Methane . . . .	CH <sub>4</sub>	68.85	75.35	2.6
Hydrogen . . .	H	.....	.....	10.5
Nitrogen . . .	N	12.90	6.60	58.2
Calorific value in B.T.U. per cu. ft.		1,000 <sup>+</sup>	1,100 <sup>+</sup>	140 <sup>+</sup>

The above analyses are of course by volume, the first analysis of natural gas being taken from normal line gas, the 8.65 per cent. of air being due merely to leakage into the main, while the second analysis of natural gas is with the air calculated out.

### ARTIFICIAL GAS

Artificial gas has been used in the form of producer gas, coal gas and water gas, but of these the only one of importance in Open *Hearth* is producer gas.



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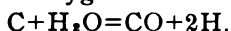
A modern producer consists essentially of a vertical steel cylinder of from 8 to 12 feet in diameter and 10 to 15 feet in height, this lined with fire brick. At the bottom is a grate on which is supported the mass of fuel about 6 to 7 feet in depth. From the top of this producer a duct leads to the main gas flue and at the base are openings for the admission of steam and air blast. There are many different types of gas producers, each having certain points of superiority, but our description has to do only with the general type.

The bed of coal being ignited, a blast of air mixed with a slight volume of steam is introduced. The carbon of the coal brought in contact with the air is burned to  $\text{CO}_2$  (carbon dioxide), the major portion of which in turn passing up through the bed of hot fuel, is broken down into carbon monoxide ( $\text{CO}$ ). A portion of the steam which is introduced at the same time is also decomposed in contact with the incandescent carbon forming hydrogen and oxygen, the latter then forming with the carbon, carbon monoxide. In addition to the above there is distilled off a certain amount of the more volatile hydro carbons from the upper portions of the coal bed. These reactions are very simply expressed as follows:

- 1st. Carbon burned to carbon dioxide.  
 $\text{C} + 2\text{O} = \text{CO}_2$ .
- 2d. Reduction of carbon dioxide by hot coal.  
 $\text{CO}_2 + \text{C} = 2\text{CO}$ .

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- 3d. Incandescent carbon decomposing water and combining with oxygen.



The steam, although broken up and forming hydrogen and carbon monoxide, both of fuel value, does not actually add to the calorific efficiency of the producer inasmuch as the reaction requires a greater expenditure of heat for its accomplishment than is available when the gases formed by its decomposition are burned, but it serves the purpose of keeping the fire at a low enough temperature to reduce the clinkering, and aids in the operation of the producer. There are of course a number of complicated secondary reactions which may occur in addition to the above, but it is unnecessary here to go into these.

It is very necessary to stir the fire at intervals of a few minutes, in order to avoid the forming of passages in the coal bed, through which the  $\text{CO}_2$  gas may pass without being kept in contact with the hot bed of fuel, and thus broken down into  $\text{CO}$ . Gases will of course take the path of least resistance, and if the bed is insufficiently stirred, either by hand or mechanical stoker, the analysis will immediately show undue percentage of  $\text{CO}_2$  in the flues. It should approximate 4 to 6 per cent.

By reference to the previous table of analyses, the reason for the comparatively low *calorific* value of producer gas is apparent in the



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large proportion of nitrogen, this unavoidable on the introduction of air. Nitrogen is inert, and its effect is merely to dilute the gas, the major portion of the fuel value of producer gas being in its content of carbon monoxide.

In what is known as a water-sealed producer, the producer itself rests in a pan containing water, into which the ashes drop, and, being water-sealed, may be cleaned and the fires attended to without interfering with the operation of the producer.

The bed of fuel, in order for the best operation of the furnace, must be maintained at approximately 6 feet in depth, this depth being kept fairly constant by fresh charges of coal introduced either by hand or by a mechanical filling device.

### FUEL FOR MAKING PRODUCER GAS

Although a number of different fuels have been used, such as anthracite coal, coke, peat, etc., bituminous coal is the only one necessary to consider here. The coal should be an ordinary good gas coal. The major portion of bituminous coals are satisfactory for use, provided they do not run too high in sulphur, preferably not over 1 per cent., although the allowable proportion of sulphur depends upon the form in which it is in the coal. If in such a state as to be very readily volatilized and pass over with the gases, a very small portion may be beyond allowable limits, as this is then very rapidly absorbed by the steel.

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but if in such form as to readily oxidize, remaining with the ash, it may be higher. Lime is sometimes added to the coal with the idea of keeping down the sulphur in the gas by formation of a sulphate. The coal should have a comparatively low percentage of ash. Other things being equal, the higher the percentage of volatile matter, the richer the gas produced, on account of the greater proportion of hydro-carbons. A gas showing ample calorific efficiency can be manufactured from anthracite coal, but in actual operation it would be exceedingly unsatisfactory. This is due to the lack of hydro-carbons carried over in the bituminous coal producer, which in the Open Hearth become incandescent, and by their radiated heat greatly increase the fuel value of the gas as compared with anthracite gas showing about the same theoretical calorific efficiency.

### OIL

In a number of Open Hearth plants, oil vaporized by steam or air, is used as a fuel, it requiring of course no previous heating. The fuel is of high heat-producing value, very easy and simple to operate, and requires a comparatively small expenditure for an outfit. Moreover, the fuel is regular in quality and the furnace can be operated very uniformly. However, with oil the flame tends to be extremely sharp and cutting, and unless proper care is exercised it is an easy matter to burn out a roof or cause *oxidization* of the metal before the trouble is



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discovered. In other words, the flame is too intense and the heat rather too much localized to be by any means ideal. Nevertheless, for reasons stated above, this system possesses a number of advantages where the supply of oil is cheap, its relative economy depending upon the relative cost of coal and oil at the plant considered, and its selection is a matter determined usually by local considerations.



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## CHAPTER III

### ACID OPEN HEARTH PROCESS

The difference between the acid and the basic Open Hearth process results in this:

That the acid process removes or reduces to within allowable limits—(1) carbon; (2) silicon; (3) manganese.

The basic process removes or reduces to within allowable limits—(1) carbon; (2) silicon; (3) manganese; (4) sulphur; (5) phosphorous.

### CHARGE

Since by the acid process no sulphur or phosphorous is eliminated, the furnace charge must be not only of no higher average percentage in these impurities than is allowable in the finished material, but somewhat lower. If, say there is an average percentage of .04 per cent. in sulphur and .06 per cent. in phosphorous in the charge, it would naturally be somewhat higher than this in the finished steel, due to the elimination of the remaining impurities.

The charge is generally made up of scrap and pig iron, in this country with usually a considerably larger proportion of scrap than abroad, where the supply of the latter is often limited, a rough average being, say 25 per cent. scrap and 75 per cent. pig iron, while in this country the more usual average will run 50 to 75 per cent. scrap and the balance pig, exact proportions dependent, however, upon the relative *availability of the pig and scrap and their cost.*



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Pig iron runs usually between 3.25 per cent. in carbon as a minimum, to 4.25 per cent. as a maximum, the silicon varying rather widely from as low as 1 per cent. or even under, up to 2.5 per cent. or over, and the manganese usually under 1 per cent. with sulphur not over .05 per cent. and phosphorous not over .10 per cent. The above of course refers to pig iron suitable for acid practice.

The scrap varies from crop ends of rails, structural shapes, billets and other heavy scrap to the lightest plate shearings, punchings, borings, turnings, etc. The following are fairly representative analyses, showing the impurities concerned in samples of pig and scrap:

Elements	Pig Iron	Structural Steel Scrap	Rail Steel Scrap
Carbon . . . .	3.00 to 4.00	.20	.45
Silicon . . . .	1.00 to 2.00	.01	.15
Manganese . . .	Under 1.00	.50	.90
Phosphorous . .	.10	.04	.10
Sulphur . . . .	.05	.04	.075

### PROPORTIONING THE CHARGE

The exact proportions of each in the charge are dependent on the quality and quantity of scrap obtainable, as well as the analysis of the pig iron, particularly its silicon content. The charge may be entirely of pig, provided a very low silicon pig be obtained; a certain proportion of pig, however, is absolutely essential to prevent the comparatively pure scrap from oxidization.

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A large proportion of high silicon pig iron and a small amount of scrap would give a large volume of slag, so much indeed as to seriously interfere with the working of the bath, forming such a heavy covering over the metal as to make it difficult to thoroughly penetrate the bath with the heat, the operation would be unduly prolonged, the slag tend to be highly viscous and pour with difficulty.

On the other hand, with too large a proportion of scrap, so small would be the amount of slag that the molten metal would have very little protecting envelop, there being, consequently, high losses from oxidization, and the charge when melted so low in silicon, manganese and carbon as to be viscid and difficult to work.

In order to proportion the charge there must first be considered at least the primary reactions which occur in the removal of the three impurities which we are alone considering in acid practice, *i. e.*, *carbon*, *silicon* and *manganese*, inasmuch as *sulphur* and *phosphorous* are supposedly within allowable limits.

The process is throughout one of oxidization, the carbon being oxidized to carbon monoxide, which in turn further oxidizes to carbon dioxide, passing off as a gas—the silicon and manganese being oxidized and forming with the manganese and iron from the bath a double silicate of manganese and iron, this rising to the top of the bath and forming a slag.

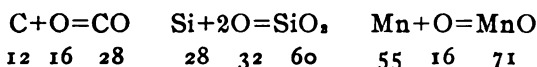
These simple reactions are expressed as follows, together with the atomic weights showing



## A STUDY OF THE OPEN HEARTH

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the proportions by weight involved in these combinations:



In other words, for the oxidization or burning of one atom of carbon there is required one atom of oxygen, but expressed by weight there will be required, because of the difference in their atomic weights, 1.333 parts of oxygen; in the same way one atom of silicon will require, by weight, 1.143 parts of oxygen; one atom of manganese will require, by weight, .291 parts of oxygen. Merely expressing this in terms of oxygen:

One part of oxygen oxidizes .750 parts of carbon, or .875 parts of silicon, or 3.438 parts of manganese.

Now, since one part of carbon requires 1.333 parts oxygen, and one part silicon 1.143 parts oxygen, one part of silicon is equivalent to  $\frac{1.143}{1.333} = .857$  carbon, *i. e.*, so far as the amount of oxygen with which it will combine is concerned. In the same way one part of manganese = .218 parts carbon.

In figuring the charge, assume that a pig and a scrap with the following fairly representative analyses are concerned:

Elements	Pig	Scrap
Carbon . . .	3.5%	.20%
Silicon . . .	1.50%	.01%
Manganese . . .	.70%	.50%

## A STUDY OF THE OPEN HEARTH

Expressing all these impurities in terms of carbon, there is in the

### *Pig Iron*

3.5% carbon		= 3.500% carbon
1.5% silicon	x .857	= 1.285% carbon
.70% manganese	x .218	= .153% carbon
Total	.	4.938% carbon

### *Scrap*

.20% carbon		= .20% carbon
.01% silicon	x .857	= .008% carbon
.50% manganese	x .218	= .109% carbon
Total	.	.317% carbon

In other words, we are dealing with a pig and scrap which require for the oxidization of their impurities the same amount of oxygen as though the pig had 4.938 per cent. carbon and no other impurities; the scrap .317 per cent. carbon and no other impurities.

The elimination of the impurities is effected in two distinct stages, *i. e.*, during the melting of the bath by the oxygen of the flame, and after the melting when this is augmented by the action of the oxides of iron formed during melting and added after melting.

For purposes of figuring the charge, assume what is a fair average, say 40 per cent. of the impurities to be oxidized during the melting (the influences governing this percentage will be taken up later under "Elimination of Impurities"). Assume also that a soft steel heat is being made, to be tapped at about .20 carbon. It should have *when melted* approximately .60 carbon. The



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problem now is, merely having a pig of total impurities, figured in terms of carbon of 4.938 per cent. and scrap .317 per cent., what proportion of the two will give an average of .60 per cent. when 40 per cent. of this total carbon has been already oxidized?

Obviously,  $.60 = 100\% - 40\% = 60\%$  or

$$\frac{.60}{.60} \times 100 = 1.00$$

which represents the total impurities (expressed in carbon) in the charge before melting, this total to be the average from the above pig and scrap.

Expressing it in per hundred parts or per cent.—:

Let  $X$  = number parts of pig.

$100 - X$  = number parts of scrap.

Then

$4.938 X$  = total impurities in pig (expressed in terms of carbon).

$.317 (100 - X)$  = total impurities in scrap (expressed in terms of carbon).

Therefore,

$$4.938 X + .317 (100 - X) = 100.0$$

$$X = 15\% \text{ pig.}$$

$$100 - 15 = 85\% \text{ scrap.}$$

### METHOD OF CHARGING

Although authorities differ as to the order in which the material is to be charged, it is almost the universal practice to charge the pig iron first

## A STUDY OF THE OPEN HEARTH

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and on it the scrap. Some charge a portion of the pig iron, then the scrap, following with the remainder of the pig.

The pig is usually, however, placed on the bottom to protect the latter from the oxide of iron formed by oxidization of the scrap by the flame. This oxide in coming into contact with the sand bottom forms a silicate of iron, very rapidly scorifying and cutting it away.

Campbell advises charging the scrap, then the pig, stating that the pig melting and trickling down over the scrap protects it from oxidization, the oxygen of the flame having a greater affinity for the carbon, silicon and manganese of the pig than for the metal itself. However, this is by no means the usual practice.

With very heavy scrap there is possibly no great advantage in one method over the other, as there is under such conditions comparatively little oxidization but with very light scrap, such as light plate shearings, it is important, for not only is the bottom rapidly scoured away by contact with the oxide of iron, but a hole may very possibly be eaten almost entirely through, and the surrounding portion of the bottom become so impregnated with iron as to greatly reduce its refractoriness. This scorification continues until the slag formed becomes either neutral or acid throughout, combining with the silica.

### ELIMINATION OF IMPURITIES

#### MELTING

In the manufacture of soft steel the charge is *often so* proportioned that practically all the



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silicon is oxidized by the time the charge is melted and the carbon is then reduced to from .60 to .80 per cent., this percentage of carbon later being reduced by the addition of ore.

In order that the flame at the beginning of melting may oxidize the scrap as little as possible, there is sometimes admitted only an insufficient supply of air, this keeping the flame smoky. It is, however, in a measure self-regulating, as the flame striking the cold stock, the gases are chilled and a portion of the carbon precipitated. Many Open Hearth men, however, believe that the best results are secured in getting the stock melted down at the earliest possible minute, even at the expense of slightly greater oxidization.

### ELIMINATION DURING MELTING

The amount of oxidization during melting is much influenced by the character of the flame, a sharp flame increasing the action; by the presence of hydrogen, which has the same effect, and by the port construction, if the ports are so inclined that the air is allowed to play directly upon the metal. This latter has a marked tendency toward increasing oxidization.

It is also apparent that the percentage of oxidization will be in a great measure dependent on the analysis of the pig iron as well as the proportions of pig and scrap, whether light or heavy, as well as the way in which it is charged. The general working of the furnace as well has also an important bearing.



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In what may be termed a normal heat, for instance for soft steel, and with the furnace under normal working conditions, the elimination of the manganese, silicon and carbon occurs in the order named and in accordance with their relative affinity for oxygen (see the combining weights under "Proportioning Charge") and in American practice, *i. e.*, with the scrap and pig here obtainable, practically all the manganese and silicon are oxidized during melting, leaving only say .60 per cent. carbon in the bath.

The following table, taken from Campbell, shows the average elimination in two series of heats, Group I of nineteen heats on producer gas; Group II of six heats with oil vapor.

### ELIMINATION OF METALLOIDS IN AN OPEN HEARTH CHARGE

Nature of Sample	Group I	Group II
Pig iron, pounds . . . . .	11,700	20,700
Steel scrap, pounds . . . . .	45,550	36,800
Composition of original charge, per cent. (estimated) . . . . .		
{ Si	.40	.65
{ Mn	.90	.85
{ C	1.00	1.50
Metal when melted, per cent. . . . .		
{ Si	.02	.05
{ Mn	.09	.06
{ C	.54	.64
Slag after melting, per cent. . . . .		
{ SiO <sub>2</sub>	50.24	49.46
{ MnO	21.67	13.16
{ FeO	23.91	33.27

In English practice where much larger proportions of pig are used, this pig running much



## A STUDY OF THE OPEN HEARTH

higher in silicon, only from 35 to 50 per cent. of the silicon will be removed during melting, and possibly 30 per cent. carbon, although nearly all the manganese will be oxidized.

In cases where a very light scrap is used, with a considerable formation of iron oxide, this may react locally to decarburize the adjacent portion of the bath before the whole is melted, but this action is not usually on so large a scale as to be important.

### ELIMINATION AFTER MELTING

There now remains in the bath, say .60 carbon (considering the soft steel heat) which must be further oxidized and dependent on conditions previously covered, there may be as well certain amounts of manganese and silicon. This carbon together with the remainder of silicon and manganese, if any, is oxidized by keeping the bath at a good heat and introducing from time to time iron ore, a red oxide, hematite, sometimes termed "vermillion" ore, being the best, this ore approximating 60 per cent. in iron, 4 to 4½ per cent. in silicon, and possibly .11 in phosphorous, with manganese running .6 per cent., lime 1.6 and with only a trace of sulphur.

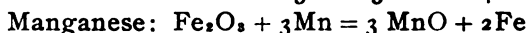
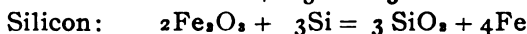
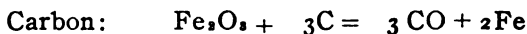
It is essential that the ore be as free as possible from impurities, and as the oxygen is the active agent, the higher the ore is in oxide of iron the more efficient it is. In order that it may penetrate the slag, reaching the metal where its work is to be done, it should be of high specific gravity and in comparatively large lumps. Otherwise,

## A STUDY OF THE OPEN HEARTH

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if in fine form, portions will become entangled in the more or less viscous slag.

The oxidization is effected in the following reactions:



The CO gas escaping as oxidization proceeds, produces a bubbling or boil over the entire surface of the bath, exposes the metal to the flame, and by its combustion serves to maintain the high temperature. If there is any silicon and manganese in the bath, due to the greater affinity for oxygen, they will be first oxidized, and when such oxidization is complete, carbon will follow.

The ore is added in small quantities from time to time as needed in the judgment of the melter, dependent not only on the quantity of impurities in the bath, but on the condition of the bath and slag, whether hot or cold, and the general working conditions of the furnace. If hot, the ore can be added much faster than if cold, when any large quantity will chill the bath. Furthermore, with a bath of high carbon, the ore does not appear to react as rapidly as when the carbon is reduced to a lower percentage, the general character of the slag also influences the rapidity of oxidization materially.

Although it is a simple matter from the equations involved in these reactions to calculate the *amount of ore necessary to oxidize any amount*

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Elements or Metalloids in the Heat	Pounds of Ore used						
	1,020	850	None	500	1,000	1,500	2,000
Per cent. carbon { after melting . . before tapping . .	.54 .08	.64 .08	.36 .08	.18 .08	.32 .08	.61 .08	.57 .08
Per cent. silicon { after melting . . before tapping . .	.02 .02	.05 .01	.03 .02	.01 .01	.04 .03	.07 .02	.09 .02
per cent. manganese { after melting . before tapping .	.09 .04	.06 .02	.06 .04	.03 .02	.05 .02	.15 .05	.15 .03



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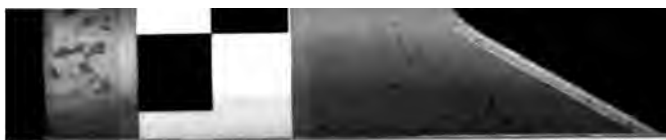
of impurities in the bath, the conditions considered have such an important effect as to render any such calculations absolutely useless, and in actual practice it is never relied upon. As of interest, however, the table on the preceding page is given, taken from Campbell's article in the "Transactions of the American Institute of Mining Engineers."

A study of this table will bear out the statements already made as to the quantities of ore required, due to conditions of stock, gas, furnace, operation, slag, etc., and apparently almost wholly independent of the amount of impurities to be oxidized. To make a general statement, one authority mentions that approximately 250 pounds of ore in a normal heat will oxidize carbon .1 per cent., but this statement is to be considered only as approximate and dependent on the conditions as cited above. It is apparent from the equations showing the reactions on introduction of the ore that a considerable amount of the metal will be by this reduction added to the bath.

After the impurities have been sufficiently oxidized by the ore additions, the bath is ready for recarburizing or recarbonizing as it is sometimes termed.

### SLAG

The slag formed from the oxidization of the impurities in the pig and scrap, the sand attached to the pig together with the impurities in the *ore*, and whatever oxide of iron may have been



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taken from the bath, serves as a covering to protect the metal from oxidization, also to transmit the heat and oxygen to the bath. Its office is an important one, and its control has a very marked bearing on the proper working of the heat.

Of course, with a high silicon pig in large proportions there is bound to be a much heavier slag than with a low silicon pig, thus with a large proportion of scrap and low silicon pig the slag may be so light as to afford scanty protection to the metal. It is important that the slag be fluid, neither pasty nor, on the other hand, too thin. Especial care is required in this at time of tapping. If too viscous, the addition of a few lumps of lime may remedy the matter; if too thin, it is an indication of a slag too rich in oxides of iron and manganese, and one liable to produce wild metal. The determination of a good tapping slag is necessarily possible only from experience.

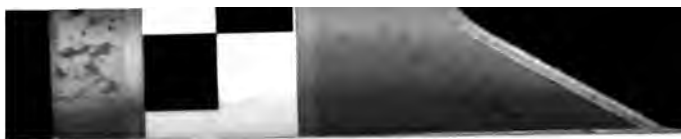
The acid slag will usually run somewhat under 10 per cent. of the total weight of the charge. The table on the following page from Campbell's article already referred to, shows the history of metal and slag in 19 and 6 heats respectively on an acid furnace.

From this it will be seen that the percentage of silica is practically constant from the time of melting to tapping, running closely around 50 per cent., and that although the MnO was less in Group II, the FeO increased, the sum of the two remaining practically constant. The slag is within certain limits almost self-regulating, i. e.,

## A STUDY OF THE OPEN HEARTH

if there is an insufficient quantity of the basic MnO and FeO to satisfy the silica, the deficiency will be made up by abstracting the iron from the bath. On the other hand, if too low in silica to satisfy the bases, the balance will be restored by silica taken from the furnace bottom. Either is objectionable, the one robbing the melt, the other scorifying the bottom. With a good working slag, *i. e.*, with sufficient oxides to satisfy this silica, and vice versa, any ore additions have practically no effect on the iron content of the slag, as the iron is merely reduced and absorbed by the bath.

Subject	Composition, Per Cent.			
	Group I 19 Heats, Soft Coal Gas		Group II 6 Heats, Oil Gas	
	After Melting	End of Operation	After Melting	End of Operation
Metal {	Si . . .	.02	.02	.05
	Mn . . .	.09	.04	.06
	C . . .	.54	.13	.64
Slag {	SiO <sub>2</sub> . . .	50.24	49.40	49.46
	MnO . . .	21.67	16.50	13.16
	FeO . . .	23.91	29.79	33.27
	MnO + FeO	45.58	46.29	46.43
				49.36
				11.30
				34.11
				45.41



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### CHAPTER IV

#### RECARBURIZATION

This term is somewhat of a misnomer inasmuch as the addition of carbon, to bring the heat to a proper percentage, is only one of the objects which may be summed up as follows :

(a) Removal or neutralization of gases and oxides retained in the heat.

After a heat is finished, with the exception of adding the recarburizer there is found to be in the metal when tapped, certain oxides of iron or other metals as well as gases, such as oxygen, hydrogen, nitrogen and carbon monoxide. These if not removed or neutralized, serve to render the metal wild, in other words, froth and bubble in the ladle and moulds and prevent a good sound ingot or casting.

(b) Introduction of metals.

For an acid Open Hearth structural steel, the specification will call for, say 50 manganese, but the entire manganese content in the pig and scrap, as has been covered, has of course been oxidized in the process of manufacture and manganese must consequently now be added.

Also certain steel castings and special steels may require very high silicon content, this introduced by the addition of certain alloys high in silica, such as silicon carbide, and in the manufacture of chrome and nickel steels there are introduced alloys of nickel and chromium.



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Aluminum is also added in small quantities to quiet the metal in the ladle and secure sounder ingots. It also promotes fluidity of the metal.

(c) Regulation of carbon content.

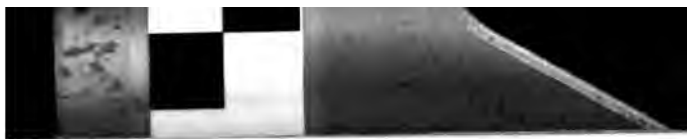
### RECARBURIZERS

Although in making structural or soft steel, such as has been previously considered, ferro-manganese is almost the only recarburizer used, there are several others such as speigeleisen, ferro-silicon, silico speigel and silicon carbide, the latter sometimes employed in the manufacture of high carbon and special steels. Ferro-manganese is an alloy of manganese, carbon and iron, standard ferro-manganese running close to 80 per cent. manganese. Speigeleisen is identical with ferro save that its manganese shows under 20 per cent. Ferro-silicon is merely a very high silicon pig iron. Silico speigel is really a combination of the latter two, having the high manganese of the former and the high silicon of the latter. All the above are made in the blast furnace, but only of course on special burdens. Silicon carbide is the product of the electrical furnace.

In addition to the above, pig metal is employed as a recarburizer, using the word in the strictest sense, and powdered coal or coke, these for the purpose of effecting the carbon only.

### METHODS OF ADDITIONS

Two methods are available for making these *additions*, *i. e.*, in the furnace or in the ladle,



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although a combination of the two is sometimes employed. Referring especially to paragraphs "a" and "b," ferro-manganese is most widely used in acid Open Hearth practice, and in addition to furnishing the necessary manganese content, it also serves to reduce whatever oxide of iron there may be in the bath, as well as to remove the free oxygen that may be held in a gaseous form, the oxide of iron being removed in its reduction to metallic iron, its oxygen going to the manganese. Ferro, as it is often termed, is often heated at least to redness before being introduced, whether in the furnace or ladle, but this is hardly necessary, as with 80 per cent. manganese the addition is comparatively a small one and has little actual effect in chilling either the bath or the metal in the ladle. This is true in heats of any considerable size, although of course if very small heats are taken, such as 3 to 5 tons and recarburized in the ladle the ferro would preferably be heated or melted before adding.

The advantage of adding the ferro-manganese in the furnace rather than in the ladle is that it can there rather better be stirred and so mingle fully with the bath, but on the other hand, manganese being very readily oxidized, there is a very considerable oxidation in the furnace and consequent loss, as the ferro is subjected, although only for a short space of time, not only to the effect of the iron oxide and gases in the metal but to the action of the flame and slag as well, and although but a

## A STUDY OF THE OPEN HEARTH

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minute or so may be required for the melting of the ferro in the bath, there is yet time for losses averaging very close to 40 per cent. of the manganese so added. If added in the ladle, on the other hand, it is apparent that such portion of the loss as is due to the contained oxides of iron, gases, etc., will be unchanged, but the manganese will not be subjected to additional oxidation by flame and slag. If added in the ladle the loss will be possibly 20 to 30 per cent.

In general, as regards the losses of manganese, since these losses are dependent not only on the oxides contained in the bath as well as the gases, but, when made in the furnace, on the condition of the slag, working of the furnace, etc., it is apparent that these losses will be as varied as are the conditions controlling them and no definite statement can be made to cover them. However, when made in the ladle it is obvious that they will be more regular.

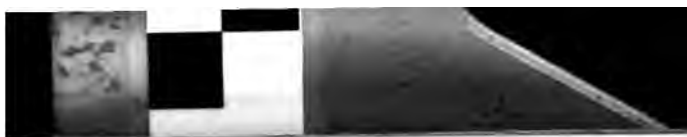
Assuming that we are working with a soft steel in which the manganese has been entirely eliminated in the operation of the heat and .50 per cent. manganese is desired in the charge, assuming also, say a 40 per cent. loss and that we are working with an 80 per cent. ferro, the heat being 30,000 pounds:

$$30,000 \times .50\% = 150 \text{ pounds manganese.}$$

Therefore, since there will be 40 per cent. loss—

$$150 \text{ pounds} = (100\% - 40\%) = 60\%$$

$$\text{or } 100\% = 250 \text{ pounds manganese.}$$



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Then with an alloy of 80 per cent. manganese there will be required:

$$250 \text{ pounds} = 80\%$$

$$\text{or } 100\% = 312.5 \text{ pounds ferro-manganese.}$$

Additions of silicon where necessary either for special steels or in order to raise the temperature for very hot metal where intricate castings must be made, may be added by any of the above mentioned high silicon alloys. The losses either in ladle or in the furnace are somewhat higher than is the case with ferro-manganese.

Aluminum is added in the ladle or in the mould in either shot or ingot form from a few ounces up to several pounds per ton of steel, dependent upon the class of steel, the purpose for which it is used, the type of ingot, etc. Inasmuch as the aluminum serves to neutralize or deoxidize the oxides which are present in the metal, consequently reducing the amount of blow-holes, it of necessity increases the size of pipe in the ingot, this pipe merely being the shrinkage cavity. In other words, it localizes the shrinkage and the exact amount which it is best to use is dependent upon the particular after-treatment which the ingot receives.

Referring to "c" (Regulation of Carbon Content), the exact method of this regulation is varied not only in the manufacture of steels of varying carbons, but in the same steels according to the particular ideas of the melter and the way the furnace may be working. In general,

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in making soft steel and using ferro as a recarburizer, it is apparent that the addition of the ferro will be so small that its carbon content will have comparatively little effect in raising the carbon of the heat. Such as it is, however, it must of course be taken care of. In making soft steel, for instance, it is often customary to boil it down to say .08 carbon and then bring back to the proper carbon for tapping by the addition of a pure pig metal charged on the sides of the hearth and allowed to run into the bath, making sure that this metal is well melted and stirred in. It may also be added in a molten state in the ladle. Another method for the addition of carbon (sometimes termed the Darby process) is by the mixture of coal or coke dust in the ladle, approximately 40 to 50 per cent. of the carbon so added being taken up by the metal, the amount however, being dependent in a great measure on the temperature, hot steel absorbing considerably more than if poured at a low temperature.

In the manufacture of hard or high carbon steels, where the carbon is, say from .40 to 1.0 per cent. it is usually the custom to "catch it coming down," *i. e.*, to stop the process at the proper point or practically there. It is often worked down a little under the desired carbon for tapping and then brought back by the addition of a little pig in the furnace or coal in the ladle. It *is seldom*, however, that it is attempted to add *all the carbon* in a heat to run over .34 or .40 in



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the ladle, although this is perfectly possible. The coal or coke when added is in the form of dust weighed out in paper sacks, so that each sack will give a definite amount.

Assume a 50-ton furnace heat, tapping for instance 109,000 pounds in the ladle, and also assuming that a carbon from .38 to .42 in the ingot is desired and that the heat has been worked down to .10 carbon, then

$$\begin{aligned} .42 - .10 &= .32 \text{ to be added;} \\ 109,000 \times .32 \text{ per cent.} &= 348.8 \end{aligned}$$

*i. e.*, when tapped from the ladle the steel is to contain 348.8 pounds more carbon than when ready to tap from the furnace.

In the best anthracite coal used for this work, but about 44 per cent. of its weight is available carbon, *i. e.*, absorbed by the steel, the balance being the ash, etc., and the large amount lost by combustion; therefore,

$$\begin{aligned} 348.8 \text{ pounds} &\text{ equal } 44 \text{ per cent.} \\ 100 \text{ per cent.} &\text{ equals } 790 \text{ pounds.} \end{aligned}$$

Therefore, there would be added in the ladle approximately 800 pounds of the crushed coal.

### TAPPING

The heat being ready to tap, a bar is driven through the tap hole and this hole then enlarged from the charging side by means of a long bar until the slag and metal flow freely.

If the hole is properly cleaned from slag and metal at the end of each heat, there will be little trouble from hard tap holes, but if proper

## A STUDY OF THE OPEN HEARTH

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precautions are not observed and a portion of slag and metal allowed to remain, this will freeze and it will be very difficult to sledge away, the bar used in drilling softening before much progress can be made.

In some instances sledging has been resorted to ten to twenty-five or even thirty-six hours before successful. In cases of this kind the following procedure has been tried with marked success. From the tapping side clean out the hole as much as possible, ram full with powdered anthracite or coke; then stir the bath directly in front of the tap hole, making it boil, when the heat from the bath penetrating the frozen metal will cause it to absorb from the coal with which the hole is plugged sufficient carbon to so lower its melting point that the hole will melt out in from one-half hour to an hour and a half. Of course, as furnace practice improves there is less and less trouble of this kind, but it will sometimes occur when apparently every care is exercised.

### SULPHUR

Although the stock selected for the heat may be amply low in sulphur, yet there is a possibility of such absorption from the gas if a sulphurous coal is used, and from the ore if high in sulphur, as to bring this element beyond allowable limits. With the same coal, however, varying amounts may be absorbed, as when the *furnace works cold* the bath is subjected for a



## A STUDY OF THE OPEN HEARTH

much longer period to the action of the gases, and due either to this or the peculiar conditions attendant upon it, sulphur is much more readily absorbed. The addition of small amounts of lime used with the coal may tend to fix the sulphur in the ash, but this addition, unless made with care, causes trouble in the producer due to the clinkering of the coal.

### SAMPLES AND TESTS

In general, in acid practice but few samples are usually necessary to follow the carbon in the bath carefully. These samples are taken merely by dipping a small quantity from the molten bath with a spoon, pouring into a mold, quenching and breaking. From the appearance of the fracture the carbon is estimated, a good melter usually coming within two or three "points" or hundredths of 1 per cent. in carbon, about .20 or under. With carbon higher than this there is greater liability to error. The first sample is sometimes taken shortly after melting, and then the melter, knowing with just what carbon he has to deal, works it down to a point he judges a little above the required carbon and takes another sample. Then when the heat is deemed ready to tap, a third may be taken and the fracture test checked up by a rapid analysis in the laboratory, requiring not more than ten minutes. The heat, if then satisfactory, is tapped.

The exact number of tests on heats varies, dependent upon the particular practice at the





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works, the way in which the furnace is running, etc., as well as upon the skill of the melter in judging his bath.

The temperature of the furnace and of the metal at its various stages is also determined largely by eye. Stirring by iron bars also gives a very good indication of the temperature of the bath, both from the "feel" of the metal, whether liquid or viscous, and from the way the bar is melted off—if clean cut, a high temperature; if rounded, lower temperature.

By the color of the slag, flame and interior of the furnace the relative temperatures are also judged.

## A STUDY OF THE OPEN HEARTH

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### CHAPTER V

#### BASIC OPEN HEARTH PROCESS

As previously noted, the result of the basic process is the removal, or reduction to within allowable limits, of carbon, silicon, manganese, sulphur and phosphorus, *i. e.*, as distinguished from the acid process, sulphur and phosphorus are in a great measure under control. This means that stock not suitable for the acid process is still available for the basic, and that the analyses of the steel will yet be in all respects satisfactory.

There are in this country vast bodies of low phosphorous ores yielding a pig iron too high in phosphorus for the acid Open Hearth, too low for the basic Bessemer, but which the basic Open Hearth can handle with no difficulty whatever, and to this is to be attributed the wonderful increase in recent years of basic Open Hearth steel production.

#### METHOD

In general, the principles and methods employed in the removal of carbon silicon and manganese are identical with those employed in acid practice, it being due only to the addition of lime, with the consequent forming of a basic slag, that there is any material departure from acid practice.

The use of this basic slag is made possible by the basic magnesite lining employed, as of course an acid lining would immediately scour away.

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### PHOSPHOROUS

Under the oxidizing influences of the flame and ore, the phosphorous is oxidized to phosphoric acid,  $2P + 5O = P_2O_5$ , which in turn, in the presence of lime, unites to form a phosphate of lime, practically stable under normal basic Open Hearth conditions, *i. e.*, where the slag is maintained strictly basic, but under certain conditions a proportion of the phosphorous may easily return to the bath if proper precautions are not observed.

### SULPHUR

Sulphur is removed partly in the slag as a sulphide of calcium,  $CaS$ , by manganese ore which may be added, and by metallic manganese with the formation of manganese sulphide,  $MnS$ . Another method for the removal of sulphur is the so-called "Saniter" process, dependent upon the use of oxychloride of lime.

### LIME ADDITION

The lime may be used in either the natural state of limestone,  $CaCO_3$  (+ impurities) or in its calcined form,  $CaO$ , from which the carbonic acid gas has been driven. On the one hand the use of the limestone with its calcination in the Open Hearth and consequent liberation of  $CO_2$ , serves to make the bath boil and insures a lively reaction and proper mingling of its elements. The  $CO_2$  gas also acts as an oxidizing agent, under these conditions allowing a



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larger quantity of pig to be used with a correspondingly larger amount of metalloids to be oxidized.

This involves the following reactions:

Carbon:  $C + CO_2 = 2 CO$ .

Silicon:  $Si + 2 CO_2 = 2 CO + SiO_2$ .

Manganese:  $Mn + CO_2 = CO + MnO$ .

On the other hand, the decomposition of  $CaCO_3$  into  $CaO + CO_2$  is one requiring the expenditure of heat which must come from the furnace and consequently retards its working to an appreciable extent. There is also undoubtedly more tendency to boiling or frothing of the slag and metal as the gases escape, and more care is necessary as to the amount of ore added that the boiling may not become too violent.

Although Campbell advocates a preliminary roasting which would decrease greatly the amount of lime necessary to charge (also necessitating more ore), it is by far the more general practice to use raw limestone. The fact that more ore is required as an oxidizing agent when the limestone is calcined before use, is in no way an argument against such preliminary roasting, however, as practically all the iron of the ore is reduced and absorbed by the bath as metal.

Although both the iron ore and the lime, each acting as oxidizing agents, are in a measure interchangeable, the lime must be in such proportions as to keep the slag distinctly basic to supply a base with which phosphorous can

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combine to form a stable compound. The phosphorous can of course unite with the iron oxide as well as with the calcium oxide, but with the former the iron will again be reduced and the phosphorous return to the bath.

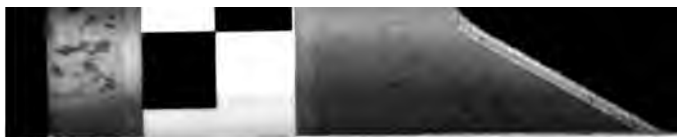
### ORE ADDITIONS

The ore performing in the basic process the same functions as in the acid, one of oxidizing, there is yet this difference, *i. e.*, it may be added at the beginning of the operation, as with a basic bottom there is no danger of its attacking this as in the acid, where the ore is usually added only after the heat is melted and the bottom protected by the bath charged with impurities. Consequently the work may be much hastened in basic practice.

### CHARGE

The same general principles covering the proportions of pig and scrap govern here as in acid practice, the exact proportions depending on the cost, quantities available and the relative analyses of the pig and scrap. However, a much larger proportion of pig can be used, as there are more oxidizing agents at work and for a longer period. Furthermore the charge may in basic practice be wholly of molten pig or "hot metal," as the bottom protected by the layer of limestone if not subject to scorification as is the acid bottom if hot metal is poured upon it.

The pig must be comparatively low in silicon, *not over say* 1 per cent. as with more than this



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the slag is so heavy as to make trouble, too large a quantity of lime being necessary to combine with the silica.

Phosphorous is so far under control that from 90 per cent. to practically all of it can be removed in the slag, so that stringent specifications in regard to this element in the pig analysis are unnecessary.

Both pig and scrap should be as low as possible in their sulphur content, inasmuch as this is by far the most difficult one of the impurities to remove in a satisfactory manner. The sulphur in the pig should run under .05 per cent.

The limestone should have as few impurities as possible inasmuch as its contents of CaO (when calcined) is the measure of the work it will perform, and it is evident that whatever proportion of silica may be in the limestone must first be satisfied by its own CaO before the balance of the oxide is available to perform its work in oxidization.

As regards the ore, it is identical with that already covered under acid practice.

Following is a typical 116,000-pound charge for 50-ton basic Open Hearth working an axle steel heat:

Molten and cast iron,

55,700 pounds = 48 per cent.

Steel scrap, 59,620 pounds = 51.5 per cent.

Additions:

Ore, 2,000 pounds = 1.7 per cent.

Ore (fed) 3,000 pounds = 2.5 per cent.

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Feldspar, 250 pounds	=	.1 per cent.
Lime, 6,800 pounds	=	5.8 per cent.
Calcined dolomite, 1,800 pounds	=	1.4 per cent.
Rods, 130 pounds	=	.1 per cent.

Additions in ladle:

Coal, 281 pounds.  
Ferro, 500 pounds.

### METHOD OF CHARGING

There is considerable variation in the matter of charging, the more common method, however, being to first charge all or practically all of the limestone, then the pig iron and lastly the scrap. This may, however, be varied by charging only a small portion of the limestone first and adding more from time to time to keep the slag strictly basic. The order of charging the pig and scrap may also be reversed.

A portion of the ore is also usually charged with the limestone and scrap, as the heat then has the benefit of its oxidizing action during the full period in which the metal is in the furnace, but it is also sometimes introduced only after the heat is melted, as in acid practice.

### ELIMINATION OF PHOSPHOROUS

The exact period at which the phosphorous is eliminated is very difficult to determine, and is, furthermore, dependent in a great measure on the particular practice followed. The following table from Campbell shows the elimination after *melting* in this particular series:

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Group	Pounds of Ore Charged with Stock per Ton of Metal	No. of Heats in Group	Composition of Metal, Per Cent.						Composition of Slag After Melting Per Cent.	
			Phosphorous			Carbon				
			Initial	After Melting	Per Cent. Eliminated	Initial	After Melting	Per Cent. Eliminated	SiO <sup>2</sup>	FeO
1	None	17	0.20	.046	77	2.00	.71	65	19.21	13.68
2	None	4	1.36	.594	57	1.50	.60	60	14.90	und.
3	None	9	0.19	.023	88	1.80	.27	85	15.55	19.68
4	None	9	0.19	.072	62	1.80	.78	57	19.98	12.20
5	300	3	2.50	.744	70	3.50	.59	83	11.96	8.61
6	115	6	0.55	.274	50	2.90	1.00	66	30.73	10.71
7	140	7	0.55	.402	27	2.90	1.48	49	34.22	10.95



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With low phosphorous it may be practically all eliminated during melting, but this does not hold good with a high phosphorous charge. It is important that this element should be removed before the carbon is down, as, with the carbon practically all oxidized, there is great difficulty in removing the last traces of phosphorous. In such a case it may be necessary to pig-back and again get the metal on the boil, adding fresh quantities of limestone to the charge.

The slag must, moreover, be kept highly basic with limestone, so that there may be ample lime with which the phosphoric acid may unite. If at any time the slag becomes too weak in this base, the phosphorous tends to return to the bath. The slag may have insufficient lime, in spite of the fact that ample quantity has been charged, due to the fact that it tends to become somewhat viscid under the heat and stick on the bottom. By the time the heat is melted the bottom must be thoroughly rabbled to make sure that all the lime is up; this not only on account of its necessary presence for the chemical reaction, but otherwise the bottom will so build up as to greatly reduce the capacity of the furnace.

A sample is taken after the charge is melted, and on quenching the fracture will show whether the elimination of the phosphorous, as well as the carbon, is proceeding satisfactorily. Too high phosphorous will show in the fracture in a crystalline form termed "phosphorous cross." *With the usual stock, however, and of fairly*



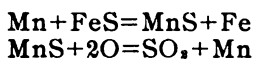
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low phosphorous metal, this element will be eliminated by the time the carbon is sufficiently oxidized.

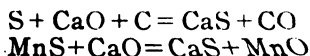
### ELIMINATION OF SULPHUR

No element is so irregular in its elimination as sulphur, the practice in some mills being to allow no higher average percentage in the stock than is allowable in the ingot. Others, however, regularly remove from 20 to 30 per cent., while by the employment of special processes as high as 50 to 75 per cent. may be eliminated.

With metallic manganese the sulphur forms a sulphide,  $MnS$ , which tends to separate from the bath, a portion being absorbed by the slag and a part may be decomposed by the heat, the sulphur burning and the manganese returning to the bath. Manganese ore, preferably added to the charge, is reduced to metallic manganese, its action in the removal of sulphur being as already indicated. The following reactions are involved:



As indicated, the portion of sulphur removed in the slag is as a sulphide. The amount is greatly dependent on the excess of lime as well as the temperature, a hot working furnace and fluid slag being always an aid. If the furnace works sluggishly, the elimination is not only less in quantity but more erratic. It involves the following reactions:



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With the use of the "Saniter" process, *i. e.*, oxychloride of lime, an exceedingly basic slag is carried previous to the introduction of the oxychloride, in fact, so basic as to have 50 to 60 per cent. of lime, and it is Campbell's suggestion that this excess basicity, together with the marked fluidity due to the oxychloride of lime, enables the slag to absorb the greater amount of sulphur.

As a whole, quantitative determinations of sulphur are throughout very difficult to make and sometimes misleading. Not only is it difficult to determine the exact proportions of sulphur in the charge, it requiring very complete and laborious sampling to get this accurately, but with producer gas and the use of a comparatively high sulphur coal, the absorption from this source introduces sulphur in unknown and sometimes excessive quantities.

### SLAG

In the basic process the slag requires probably somewhat more careful watching than in acid. Not only is its volume much greater, but, contrary to acid practice, one of its impurities already oxidized may, unless the slag has proper attention, return to the bath.

Its composition includes of course the silica from the oxidization of the silica in the pig iron, and any present, as impurities, in the limestone, *ore, etc.*, oxides of calcium, iron and manganese,



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the latter from the pig and also from the manganese ore sometimes added; also alumina from the impurities in the lime, ore, dolomite, etc., as well as magnesia taken up from the bottom, together with whatever phosphorous may have been oxidized and held, as phosphoric acid, and subsequently as phosphate of lime, together with a variable amount of sulphur in the form of calcium sulphide.

The two primary essentials in basic slags are basicity and fluidity. On the basicity depends its power to hold and take up sulphur and phosphorous, and unless sufficiently basic it will also rapidly cut away the bottom. It must be fluid in order to properly work the heat, pour cleanly from the bottom, in order that the latter may not fill up, and last, but by no means least, on its fluidity as well as its basicity depends in a very great measure its ability to remove the phosphorous and sulphur. Such oxides of iron and manganese as are present tend to render the slag more fluid, while the magnesia increases its viscosity. If too thick, the slag may be thinned by the addition of a little calcium fluorspar, calcium fluoride,  $\text{CaF}_2$ . This increases the fluidity without lowering its basicity. Manganese ore is also sometimes used with the additional advantage that it is a de-sulphurizing agent. Silica in the form of brickbats, often employed for this purpose in acid practice, would be here entirely unsuitable, as the slag, though rendered more fluid, would be also less basic, and not only

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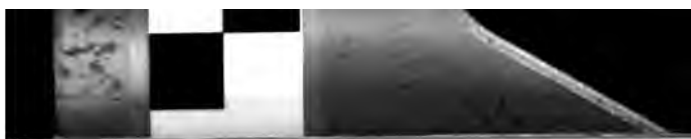
retard the de-phosphorization, but allow a portion of the phosphorous already oxidized to return to the metal. Such a slag would also rapidly erode the bottom and walls at the slag line.

Some explanation is due for the presence of oxide of iron in the slag, as there is an excess of calcium oxide to satisfy the silica. The idea advanced by Campbell is that slags tend to combine with whatever will promote their fluidity. A slag made up almost wholly of silicate of lime is very viscous, consequently seizes upon the iron as conferring fluidity. Without going into detail his conclusion is that the regulation of the percentage of  $\text{SiO}_2 + \text{FeO}$  in the slag is practically automatic.

The following analyses show typical basic slags from normal axle steel heats, the charge being made up of 47 per cent. molten, or cast iron, and 51 per cent. steel scrap.

<u><math>\text{SiO}_2</math></u>		<u><math>\text{FeO}</math></u>		<u><math>\text{P}_2\text{O}_5</math></u>
11.50	. .	16.66	. .	2.97
12.40	. .	18.39	. .	1.68
13.70	. .	17.78	. .	2.35
16.20	. .	14.73	. .	2.07
13.20	. .	15.24	. .	2.85
14.10	. .	21.34	. .	2.67
23.40	. .	11.68	. .	3.48

and the more complete analysis of slag ready to tap, showing:



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SiO <sub>2</sub>	.	.	.	10.80 per cent.
FeO	.	.	.	22.01 per cent.
Al <sub>2</sub> O <sub>3</sub>	.	.	.	1.55 per cent.
P <sub>2</sub> O <sub>5</sub>	.	.	.	5.61 per cent.
MnO	.	.	.	9.00 per cent.
CaO	.	.	.	44.00 per cent.
Mgo	.	.	.	6.53 per cent.

### REMOVAL OF SLAG

When the ore is charged with the stock, there is of course a very considerable oxidizing action, the slag in the earlier stages containing often large percentages of phosphoric acid. Both on account of the large volume of slag, the use of both ore and limestone tending to make it foam, and the liability of the phosphoric acid once in the slag returning to the metal, removal of the slag, partial or entire, has often been suggested. In an ordinary furnace, however, this is difficult to do without wasting metal, as the slag line is often very variable, and if tapped low enough to get all, a small portion of the metal is often brought with it. It is, nevertheless, regularly done at some plants, particularly where rolling or tilting furnaces are used.

### RECARBURIZATION

This is practically identical with recarburization in acid practice. It is very common, however, in basic practice to have in the decarburized metal considerable content of manganese either from manganese ore introduced to promote fluidity and the removal of sulphur, or from the stock,



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and due account must be taken in the ferro addition. Furthermore, any carbon added must be made in the ladle, as, if the heat is recarburized in the furnace in contact with the slag, a portion of the phosphorus may return to the bath.



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### CHAPTER VI

#### SPECIAL PROCESSES

##### TALBOT PROCESS

What is often termed the Continuous Open Hearth process was patented by Talbot, of Pencoyd, in 1899. In this process a modified tilting or rolling open hearth of large capacity is used, often holding 200 tons or over.

The initial charge of scrap and pig is worked in the usual manner, but when ready to tap, say only 25 to 30 per cent. of the purified metal is withdrawn.

To the remaining metal is added oxide of iron in the form of roll scale, mill cinder or iron ore. After this is melted and incorporated in the slag, hot metal and limestone are added, the addition equalling in amount that already tapped.

Due to the slag, now very rich in oxides of iron, the reactions are violent and purification is very quickly effected, the percentage of impurities in the hot metal added being of course much reduced by dilution with the metal already purified in the furnace. The above additions are made not at once, but at intervals, dependent upon the particular practice and the violence of the reactions. This process is repeated as often as the metal is sufficiently purified; at the end of the week, however, it is usual to tap the entire charge and make necessary repairs. The essential principle involved in the exceptionally vigorous reactions brought about upon the hot



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metal by the slags, exceptionally high in metallic oxides and consequently readily reducible by the metalloids of the bath. This method of operation has the advantage of being applicable to the pig and ore process, of allowing considerable variation in the analysis of the metal used, and of producing a large tonnage. It is particularly desirable where economy of space is necessary.

### MONELL PROCESS

This is essentially that of the Talbot, *i. e.*, dependent upon the strong oxidizing action of a slag rich in oxides of iron. It is carried on in the usual stationary furnace, charging the limestone and iron oxides first, heating them until almost melted and then adding the molten pig. After purification the entire heat is tapped. In tapping the entire heat, the heavy and corrosive slag necessarily comes more in contact with the furnace bottom than in the Talbot process, and consequently careful attention to bottom repairs is necessary,

### BERTRAND-THIEL PROCESS

This has been developed abroad and is especially adapted to high phosphorous pig iron. Two furnaces of the ordinary type are involved. Into the first is charged molten pig or pig and scrap, ore and limestone, in the usual manner. The ensuing reaction removes all the silicon, by far the larger percentage of phosphorous and a *portion of the carbon*. The metal is then tapped



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into the second furnace, in which is an additional charge of lime and ore, together usually with a certain amount of scrap, all heated to point of fusion, and care being taken that none of the slag from the first furnace enters. Here purification is completed.

In this process the highly oxidizing action of a slag rich in oxides of iron is again made available, together with the removal of the first slag holding the major portion of the phosphorous, thus eliminating any chance of its return.

### DUPLEX PROCESS

This is simply a combination of the Bessemer and the Open Hearth, and is particularly applicable to pig iron containing too high silicon for advantageous working in either basic Bessemer or basic Open Hearth.

In the acid Bessemer converter the preliminary blast removes the silicon, together with a considerable proportion of the manganese and a certain amount of the carbon. The desiliconized metal is then transferred to the basic Open Hearth, where the phosphorous and the remainder of the carbon is eliminated in accordance with the usual practice.

This process has been employed in this country mainly in the South, where the ores are such as to produce pig iron adapted to this treatment.









